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Dated 21 JAN 1998

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Request for grant of a patent

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04 JAN 1997

The Patent Office

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1. Your reference — 277P96.045

- 4 JAN 1997

2. Patent application number *(The Patent Office will fill in this part)* — 9700090.5

3. Full name, address and postcode of the or of each applicant. *(underline all surnames)*

Professor Jim Horne
9 The Drive, Woodhouse Eaves,
Leicestershire, LE11 3TU
7130622001

Patents ADP number *(if you know it)*

If the applicant is a corporate body, give the country/state of its incorporation

Dr Louise Reyner
20 Station Road, Quorn,
Leicestershire, LE12 8BS
7130610001

trading as Sleeptec

4. Title of the invention

Sleepiness Detection for Vehicle Driver

5. Name of your agent *(if you have one)*

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

Chris J Tillbrook & Co
5 Old Rectory Close, Churchover,
Rugby, Warwickshire, CV23 0EN

6475612001

Patents ADP number *(if you know it)*

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing *(day / month / year)*

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:*
   a) any applicant named in part 3 is not an inventor, or
   b) there is an inventor who is not named as an applicant, or
   c) any named applicant is a corporate body
   See note (d))

No

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form	0
Description	11
Claim(s)	2
Abstract	1
Drawing(s)	9

10. If you are also filing any of the following, state how many against each item.

Priority documents	0
Translations of priority documents	0
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	0
Request for preliminary examination and search *(Patents Form 9/77)*	0
Request for substantive examination *(Patents Form 10/77)*	0
Any other documents *(please specify)*	0

11. I/We request the grant of a patent on the basis of this application.

Chris J Tillbrook & Co

Signature Chris J Tillbrook & Co Date 3 January 1997

12. Name and daytime telephone number of person to contact in the United Kingdom Sian Hughes 01926 490929

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Sleepiness Detection for Vehicle Driver

This invention relates to human sleepiness, drowsiness or (lack of) alertness detection and monitoring, to provide a warning indication in relation to the capacity or fitness to drive or operate moving machinery.

Although its rationale is not fully understood, it is generally agreed that sleep is a powerful and vital, biological need, which if ignored can be more incapacitating than realised.

As such, the invention is particularly, but not exclusively, concerned with the sleepiness and performance-impaired fatigue of drivers of motor vehicles upon the public highway.

Professional drivers of, say, long-haul freight lorries or public transport coaches are especially vulnerable to fatigue, loss of attention and driving impairment.

With this mind, their working and active driving hours are already carefully monitored to ensure they are within prescribed limits.

Road accidents, some with no apparent external cause, have been attributed to driver fatigue.

Studies (see the appended references) into sleep-related vehicle accidents by the Applicants themselves have concluded that such accidents are largely dependent on the time of day.

Age may also be a factor - with young adults more likely to have accidents in the early morning, whereas older adults may be more vulnerable in the early afternoon.

Drivers may not recollect having fallen asleep, but may be aware of a precursory sleepy state, as normal sleep does not occur spontaneously without warning.

The present invention addresses sleepiness monitoring, to engender awareness of a state of sleepiness, in turn to prompt safe countermeasures, such as stopping driving and having a nap.

Accidents have also been found to be most frequent on monotonous roads, such as motorways and other main roads.

Indeed, as many as 20-25% of motorway accidents seem to be as a result of drivers falling asleep at the wheel.

Although certain studies concluded that it is almost impossible to fall asleep while driving without any warning whatsoever, drivers frequently persevere with their driving when they are sleepy and should stop.

Various driver monitoring devices have been proposed to assess fatigue, such as

eyelid movement detectors, but the underlying principles are not well-founded or properly understood.

Sleepiness in the context of driving is problematic because the behavioural and psychological processes which accompany falling asleep at the wheel may not typify the characteristics of sleep onset commonly reported from sleep laboratories.

Driving will tend to make a driver put considerable effort into remaining awake, and in doing so, the driver will exhibit different durations and sequences of psychological and behavioural events that precede sleep onset.

As underlying sleepiness may be masked by this compensatory effort, the criteria for determining whether a subject is falling asleep may be unclear.

Indeed, the Applicants have determined by practical investigation that parameters usually accepted to indicate falling asleep are actually not reliable as an index of sleepiness if the subject is driving.

For example, although in general eye blink rate has a tendency to rise with increasing sleepiness, this rate of change is confounded by the demand level of a task undertaken (eg driving), there being a negative correlation between blink rate and task difficulty.

In an attempt to prevent sleep-related vehicle accidents, it is also known passively to monitor driver working times through chronological activity logs, such as tachographs. However, these provide no active warning indication.

More generally, it is also known to monitor a whole range of machine and human factors for vehicle engineering development purposes, but again these are for historic data accumulation, not active warning.

The Applicants are not aware of any practical implementation hitherto of sleepiness detection, using relevant and proven biological factors addressing inherent body condition and capacity.

Studies and trials carried out by the Applicants have shown that there are clear discernible peaks of sleep-related vehicle accidents in the UK around 02.00-06.00 hours and 14.00-16.00 hours.

Similar time-of-day data for such accidents have been reported for the USA, Israel and Finland.

These sleep-related vehicle accident peaks are distinct from the peak times for all road traffic accidents in the UK - which are around the main commuting times of 08.00 hours and 17.00 hours.

The term 'sleepiness' is used herein to embrace essentially pre-sleep conditions, rather than sleep detection itself, since, once allowed to fall asleep, it may be too late to

provide useful accident avoidance warning indication or correction.

Generally, a condition or state of sleepiness dictates a lessened awareness of surroundings and events and a reduced capacity to react appropriately and an extended reaction time.

It is known from sleep research studies that the normal human body biological activity varies with the time of day over a 24 hour, (night-day-night) cycle - in a characteristic regular pattern, identified as the circadian rhythm or body clock.

The human body thus has a certain pre-disposition to drowsiness or sleep at certain periods during the day, in particular in the early hours of the morning and mid afternoon.

This is exacerbated by consumption of alcohol, rather than necessarily food *per se*.

According to one aspect of the invention
a system imparting knowledge of circadian and sleep parameters
of an individual vehicle driver,
is integrated with road condition monitoring and driver control action,
including steering and acceleration,
to provide an (audio-) visual indication of sleepiness.

In this way, say, aberrant steering behaviour, associated with degrees of sleepiness, could be recognised and corrected - or at least a warning of the need for correction issued.

Pragmatically, any sleepiness warning indication should be of a kind and in sufficient time to trigger corrective action.

According to another aspect of the invention,
a driver sleepiness condition
or fitness monitor comprises
a plurality of sensory inputs,
related to vehicle motion,
biorhythmic patterns,
and recent driver experiences and pre-conditioning,
such inputs being individually weighted
according to contributory importance,
and combined in an algorithm or model,
to provide a warning indication of sleepiness.

Some embodiments of the invention can take into account actual vehicle driving actions, such as use of steering and accelerator, and integrate them with inherent biological factors and current personal data, for example recent sleep pattern, age, sex, recent alcohol consumption (within the legal limit), reliant upon input by a driver being monitored.

Steering action is best assessed when driving along a relatively straight road, such as a trunk, arterial road or motorway, when steering inputs of an alert driver are characterised by frequent, minor correction.

In this regard, certain roads have characteristics, such as prolonged 'straightness', which are known to engender or accentuate driver sleepiness.

It is envisaged that embodiments of the steering detector will also be able to recognise when a vehicle is on such (typically straighter) roads.

Some means, either automatically through a steering sensor, or even from manual input by the driver, is desirable to recognised motorway as opposed to, say, town driving conditions, where large steering movements obscure steering irregularities or inconsistencies.

Indeed the very act of frequent steering tends to contribute to, or stimulate, wakefulness.

In practice, having recognised the onset of journeys on roads with an enhanced sleepiness risk factor, journey times on such roads beyond a prescribed threshold - say 10 minutes - could trigger a steering action detection mode, with a comparative test against a steering characteristic algorithm, to detect sleepy-type driving, and issue a warning indication in good time for corrective action.

As another vehicle control condition indicator, accelerator action, such as steadiness of depression, is differently assessed for cars than lorries, because of the different spring return action.

In assessing driver responses, reliance is necessarily placed upon the good intentions, frankness and honesty of the individual.

A practical device would embody a visual and/or auditory display to relay warning messages and instructions to and responses from the user.

Similarly, interfaces for vehicle condition sensors, such as those monitoring steering and accelerator use, would be incorporated.

Furthermore, input (push-button) switches for driver responses would also feature - conveniently adjacent the visual display.

Input effort would be minimal to encourage participation, and questions would be straightforward and direct, to encourage explicit answers.

Visual display reinforcement messages could be combined with the auditory output.

Ancillary factors, such as driver age and sex, could also be input.

An interface with a global positioning receiver and map database could also be

envisaged, so that the sleepiness indicator could register automatically roads with particular characteristics, including a poor accident record, and adjust the monitoring criteria and output warning display accordingly.

The device could be, say, dashboard or steering wheel mounted, for accessibility and readability to the driver.

Ambient external light conditions could be sensed by a photocell. Attention could thus be paid at night to road lighting conditions.

Vehicle driving cab temperature could have a profound effect upon sleepiness, and again could be monitored by a localised transducer at the driver station.

The device could categorise sleepiness to an arbitrary scale. Thus, for example, the following condition levels could be allocated:

ALERT
A LITTLE SLEEPY
NOTICEABLY SLEEPY
DIFFICULTY IN STAYING AWAKE
FIGHTING SLEEP
WILL FALL ASLEEP

Personal questions could include:

QUANTITY OF SLEEP IN THE LAST 24 HOURS
QUALITY OF THAT SLEEP IN THE LAST 24 HOURS

Road conditions could include:

MOTORWAY
MONOTONOUS
TOWN

Night-time with no street lights could be given a blanket impairment rating or loading.

Assumptions are initially made of no alcohol consumption whatsoever (ie legal limits disregarded).

A circadian rhythm model allows a likelihood of falling asleep, or a sleep propensity, categorised between levels 1 and 4 - where 4 represents very likely and 1 represents unlikely.

The lowest likelihood of sleepiness occurs from mid morning to early afternoon.

Thereafter a mid afternoon lull, or rise in likelihood of sleepiness to 3 is followed by another trough of 1 in early evening, rising stepwise towards late night, through midnight and into the early hours of the morning.

There now follows a description of some particular embodiments of the invention, by way of example only, with reference to the accompanying diagrammatic and schematic drawings, in which:

Figure 1 shows the circuit layout of principal elements in a sleepiness monitor for a road vehicle driver;

Figure 2 show an installation variation for the indicator and control unit of the sleepiness monitor shown in Figure 1;

Figure 3 shows a graph of variation in susceptibility to sleepiness over a 24 hour period, reflecting human body circadian rhythm patterns;

Figures 4 through 9 show pairs of personal performance graphs reflecting steering wheel inputs for three individual drivers, each pair representing comparative alert and sleepy (simulated) driving conditions.

Referring to the drawings, a sleepiness monitor 10 is integrated within a housing 11, configured for ease of in-vehicle installation, for example as a dashboard mounting, or, as depicted in Figure 2, mounted on the steering wheel itself.

In a preferred variant, the monitor 10 could be self-contained, with an internal battery power supply and all the necessary sensors fitted internally, to allow the device to be personal to a driver and moved with the driver from one vehicle to another.

An interface 19, for example a multi-way proprietary plug-and-socket connector, is conveniently provided in the housing, to allow interconnection with an additional external vehicle battery power supply and various sensors monitoring certain vehicle conditions and attendant driver control action.

Thus a steering wheel movement sensor 13 monitors steering inputs from a driver (not shown) to a steering wheel 12.

The sensor 13 could be located within the steering wheel and column assembly.

Similarly, an accelerator movement sensor 15 monitors driver inputs to an accelerator pedal 14.

The sensor 15 could be an accelerometer located within the housing 11 in a self-contained variant.

Alternatively, but less conveniently, vehicle motion and acceleration could be recognised through a transmission drive shaft sensor 27, coupled to a vehicle road wheel 26 or by interfacing with existing sensors or control processors for other purposes, such as engine and transmission management.

The trend to multiplex vehicle wiring harnesses, relaying data between vehicle

operational modules, may facilitate such interconnection.

The device could have an internal memory of speed and steering wheel movements and a 'decision' history.

The interface 19 would enable data to be down-loaded onto a PC via, say, the PC parallel port or over a radio or infra-red 'wireless' link.

A further photocell sensor 29 monitors ambient light conditions from the driving position and is calibrated to assess both day-night transitions and the presence or absence of street lighting at night.

Reverting to the unit itself, the housing 11 incorporates a visual display panel or screen 18, for relaying instructions and warning indications to the user.

A loudspeaker 21 can relay reinforcement sound messages, for an integrated audio-visual driver interaction.

Also to that end, in a more sophisticated variant - possibly merely as an ongoing research and development tool, a microphone 23 might be used to record and interpret driver responses, possibly using speech recognition software.

Alternatively, interactive driver interrogation and response can be implemented a series of push button switches 16 arrayed alongside the screen 18, for the input of individual driver responses to preliminary questions displayed upon the screen 18.

Thus, for example, non-contentious factors, such as driver age and sex may be accounted for, together with more subjective review of recent sleep history.

Questions would be phrased concisely and unequivocally, for ease and immediacy of comprehension and certainty or authenticity of response.

Thus, for example, on the pivotal contributory factor of driver's recent sleep, the question:

'How much sleep have you had in the last 24 hours'

could be juxtaposed with a multiple choice on screen answer menu, such as:

Choice of ONE answer ...

Little or none ... [generating a weighting score of 2]
Less than normal ... [score 1]
About the same as normal, undisturbed ... [score 0]
About the same as normal, but disturbed ... [score 1]

Other contributory factors include road conditions and vehicle cabin temperature.

Road conditions would be assessed through the steering sensor 13, and through an initial input question upon road conditions.

Thus, a dull, monotonous road would justify a weighting of plus 1 to all the circadian scores.

On the other hand, town driving, promoting greater alertness from external stimuli, would merit a score of minus 1.

Vehicle cabin temperature is taken into account, primarily to register excessively high temperatures which might induce sleepiness.

Driver cab temperatures could be monitored with a temperature sensor probe 31 (located away from any heater output vents).

Thus, for example, a threshold of some 25 degrees C might be set, with temperatures in excess of this level triggering a score of plus 0.5.

In normal operating mode, the monitor relies upon the working assumption that the driver has had little or no recent or material alcohol consumption.

The circadian rhythm template pre-loaded into the monitor memory is adjusted with the weighting scores indicated.

If the cumulative score is equal to or greater than 3, the steering sensor is actively engaged and checked to determine the road conditions.

The sleepiness scale values, reflected in the unweighted graph of Figure 3, can broadly be categorised as:

1. ALERT
2. NEITHER ALERT NOR SLEEPY
3. A LITTLE SLEEPY
4. NOTICEABLY SLEEPY
5. DIFFICULTY IN STAYING AWAKE
6. FIGHTING SLEEP
7. WILL FALL ASLEEP

An internal memory module may store data from the various remote sensors 13, 15, 27, 29, 31 - together with models or algorithms of human body circadian rhythms and weighting factors to be applied to individual sensory inputs.

A microprocessor is programmed to perform calculations according to driver and sensory inputs and to provide an appropriate (audio-)visual warning indication of sleepiness through the display screen 18.

Figure 2 shows a steering-wheel mounted variant, in which the housing 11 sits between lower radial spokes 27 on the underside of a steering wheel 12 - in a

prominent viewing position for the driver, but not obstructing the existing instrumentation, in particular speedometer, nor any air bag fitted.

Ambient temperature and lighting could also be assessed from this steering wheel vantage point.

This location also facilitates registering of steering wheel movement. With an internal accelerometer and battery, external connections could be obviated.

Whilst a motor vehicle orientated monitor has been disclosed in the foregoing example, the operating principles are more widely applicable to moving machine-operator environments, as diverse as cranes, construction site excavators and drilling rigs - possibly subject to further research and development.

Figures 4 through 9 show the respective steering 'performances' of three individual subjects, designated by references S1, S2 and S3, under alert and sleepy (simulated) driving conditions.

Each graph comprises two associated plots, representing steering wheel movement in different ways.

Thus, one plot directly expresses deviations of steering wheel position from a straight-ahead reference position - allotted a 'zero' value.

This plot depicts the number of times a steering wheel is turned in either direction, over a given time period - allowing for a +/- 3% 'wobble' factor as a 'dead' or neutral band about the reference position.

The other plot is an averaged value of steering wheel movement amplitude (ie the extent of movement from the reference position) - using the RMS (root mean squared) of the actual movements.

Generally, the graphs reflect a characteristic steering performance or behaviour.

In particular, as a person becomes sleepy, zero crossings are reduced in frequency, whereas RMS amplitudes increase and/or become more variable.

Thus, Figure 4 reflects steering behaviour of an alert subject S1.

Collectively, the 'zero-crossing' and 'RMS' plots for alert subject S1 reflect a generally continual and consistent steering correction.

In contrast, the steering behaviour of a sleepy subject S1, reflected in Figure 5, exhibits less frequent, erratic, exaggerated or excessive steering movement.

Figure 6 reflects steering behaviour for another alert subject S2, whilst Figure 7 shows the corresponding readings when the same subject was sleepy.

Figure 8 reflects steering behaviour of yet another alert subject S3 and Figure 9 that of a sleepy subject S3.

Each pair of graphs shows corresponding marked differences in steering behaviour between an alert and sleepy driver.

This characteristic difference validates the use of actual or real-time dynamic steering behaviour to monitor driver sleepiness.

In a practical system, using steering wheel movement to identify sleepiness, on the basis of such findings, it is preferred that, <u>before</u> presenting a sleepiness warning indication, at least two of the following three sleep categorising conditions of steering behaviour are present, namely:

1. Fewer zero crossings;

2. RMS amplitude high;

3. RMS more variable.

Component List

10	(sleepiness) monitor
11	housing
12	steering wheel
13	steering position/movement sensor
14	accelerator pedal
15	accelerator position/movement sensor
16	push-button switch
17	steering wheel spokes
18	display panel/screen
19	interface connector
21	loudspeaker
23	microphone
26	road wheel
27	(drive) shaft sensor
29	photocell sensor
31	temperature probe

Literature References

1. J. Sleep Research 1994 vol 3 p195; 'Accidents & Sleepiness': consensus of Stockholm International Conference on work hours, sleepiness and accidents.

2. J. Sleep Research 1995 suppl. 2 p23-29; 'Driver Sleepiness': J.A. Horne & L.A. Reyner Sleep Research Laboratory, Loughborough University

3. British Medical Journal 4 March 195 vol 310 p565-567; 'Sleep related vehicle accidents': J.A. Horne & L.A. Reyner

Claims

1.

A sleepiness monitor (10), for a vehicle driver, or machine operator, comprising a plurality of sensors (13, 15, 27, 29), for registering vehicle or machine condition factors, and attendant driver or operator control actions or inputs, a personal data entry interface, a memory for loading with a circadian body rhythm reference model, a microprocessor or other computation engine, an operating model or algorithm, for weighting the circadian rhythm model, according to sensory inputs, and providing a warning indication (18) of driver or operator sleepiness.

2.

A sleepiness monitor, as claimed in Claim 1, including a sensor for vehicle steering wheel movement.

3.

A sleepiness monitor, as claimed in either of the preceding claims, including a sensor for vehicle acceleration and/or speed.

4.

A sleepiness monitor, as claimed in any of the preceding claims, including a sensor for vehicle cab temperature.

5.

A sleepiness monitor, as claimed in any of the preceding claims, including a sensor for ambient light.

6.

A sleepiness monitor, as claimed in any of the preceding claims, including provision, for example by way of push button switches, for input of responses to predetermined questions on driver condition, such as recent sleep history.

7.

A sleepiness monitor, substantially as hereinbefore described, with reference to, and as shown in, the accompanying drawings.

8.

A vehicle or machine, incorporating a sleepiness monitor, as claimed in any of the preceding claims.

Abstract

A vehicle driver or machine operator sleepiness monitor (10), optionally configured as a self-contained module (11), provides for individual driver interrogation and response, combined with various sensory inputs (13, 15, 27, 29) on vehicle condition and driver control action, and translates these inputs into weighting factors to adjust a biological activity circadian rhythm reference model, in turn to provide a sleepiness warning indication on a visual display screen (18) - which may be dashboard or steering wheel mounted.

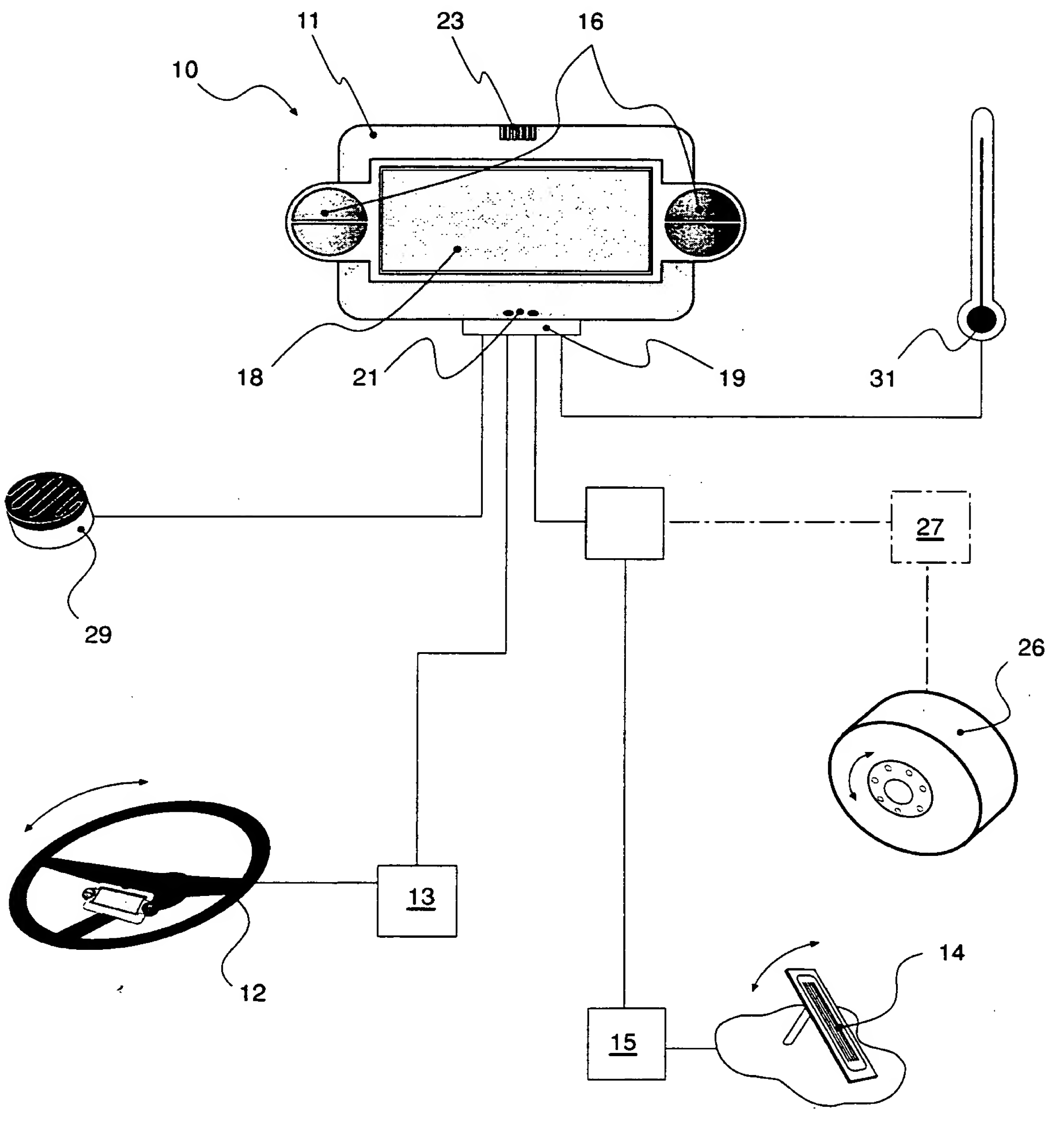


Fig 1

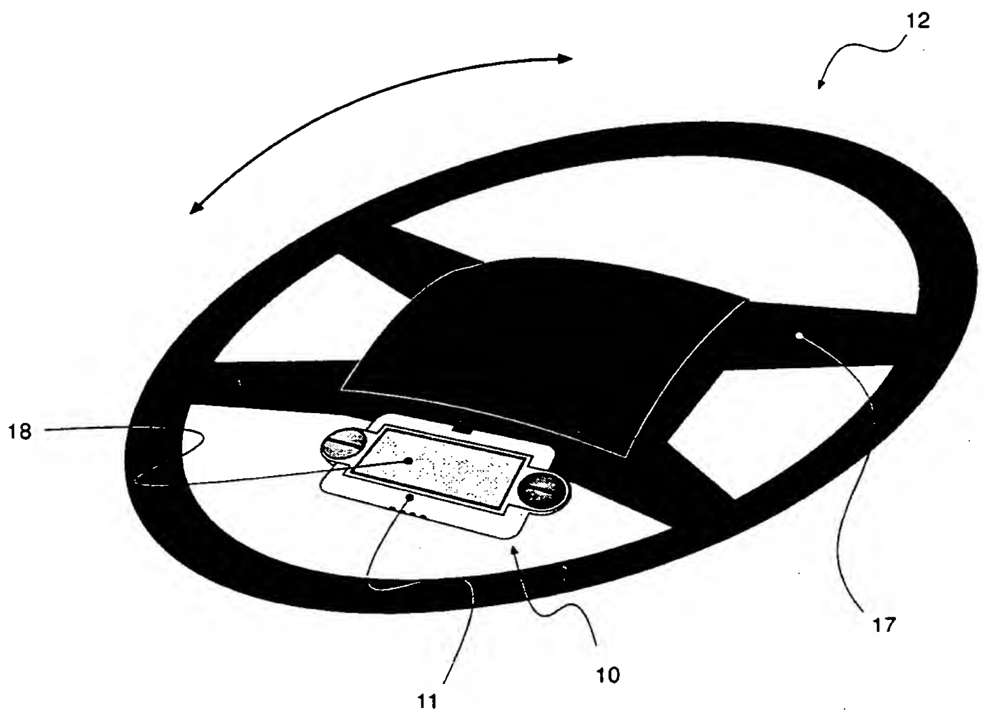


Fig 2

LIKELIHOOD OF FALLING ASLEEP 1= unlikely, 2= possibly, 3= likely, 4= very likely, 5= certain

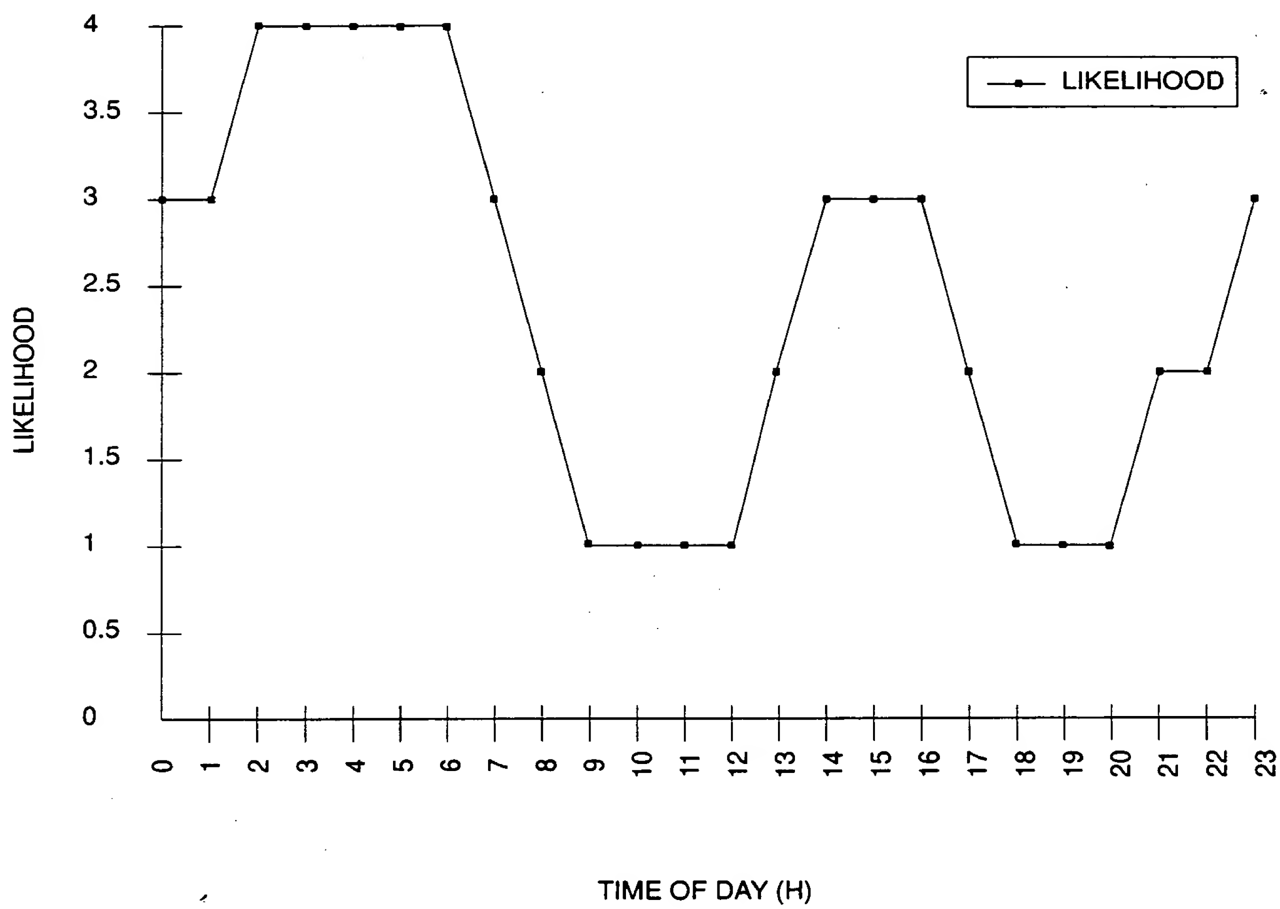
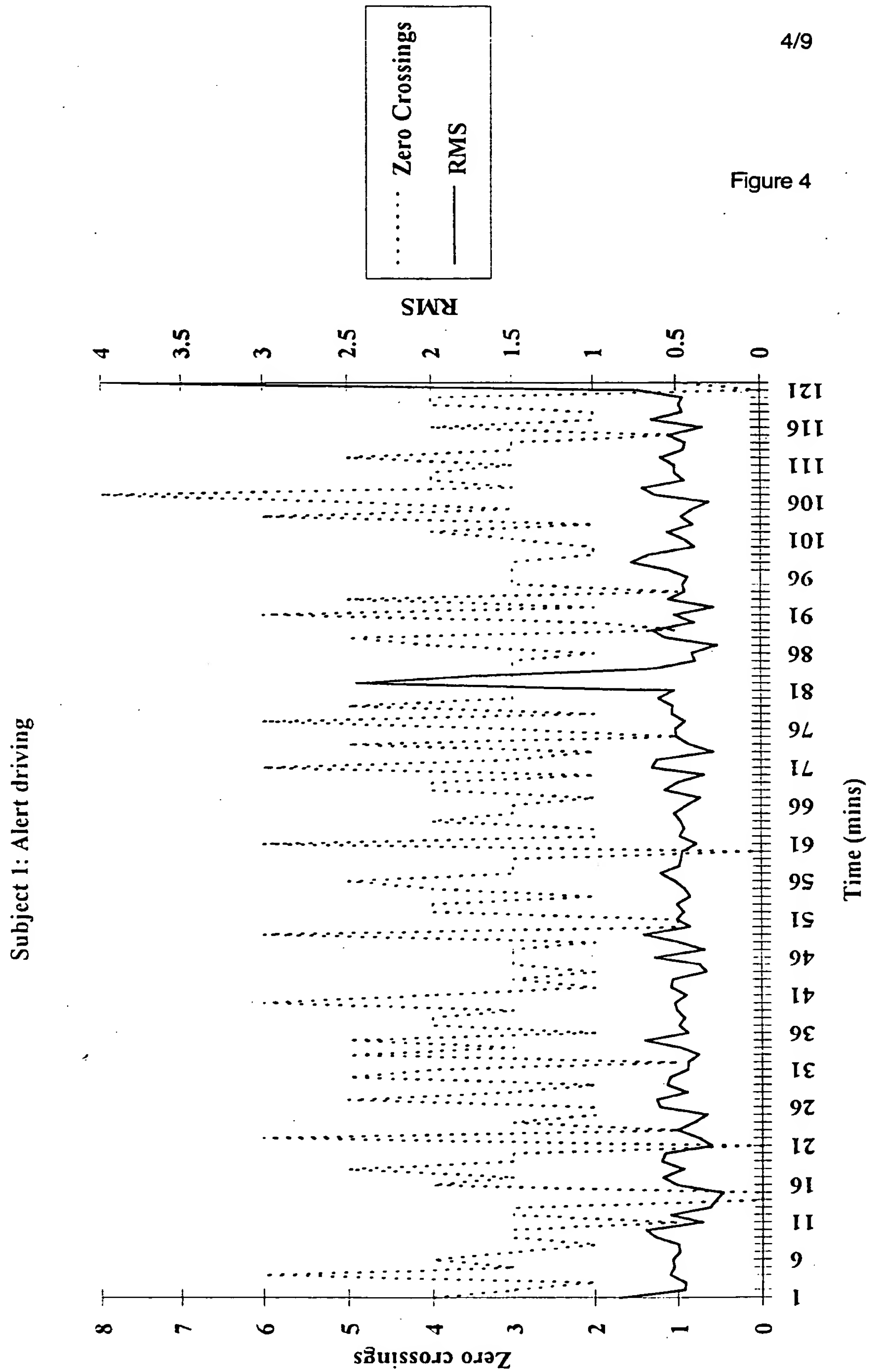


Fig 3

Figure 4


Subject 1: Alert driving
Zero Crossings
RMS
Zero crossings
Time (mins)
8
7
6
5
4
3
2
1
0
4
3.5
3
2.5
2
1.5
1
0.5
0
1
6
11
16
21
26
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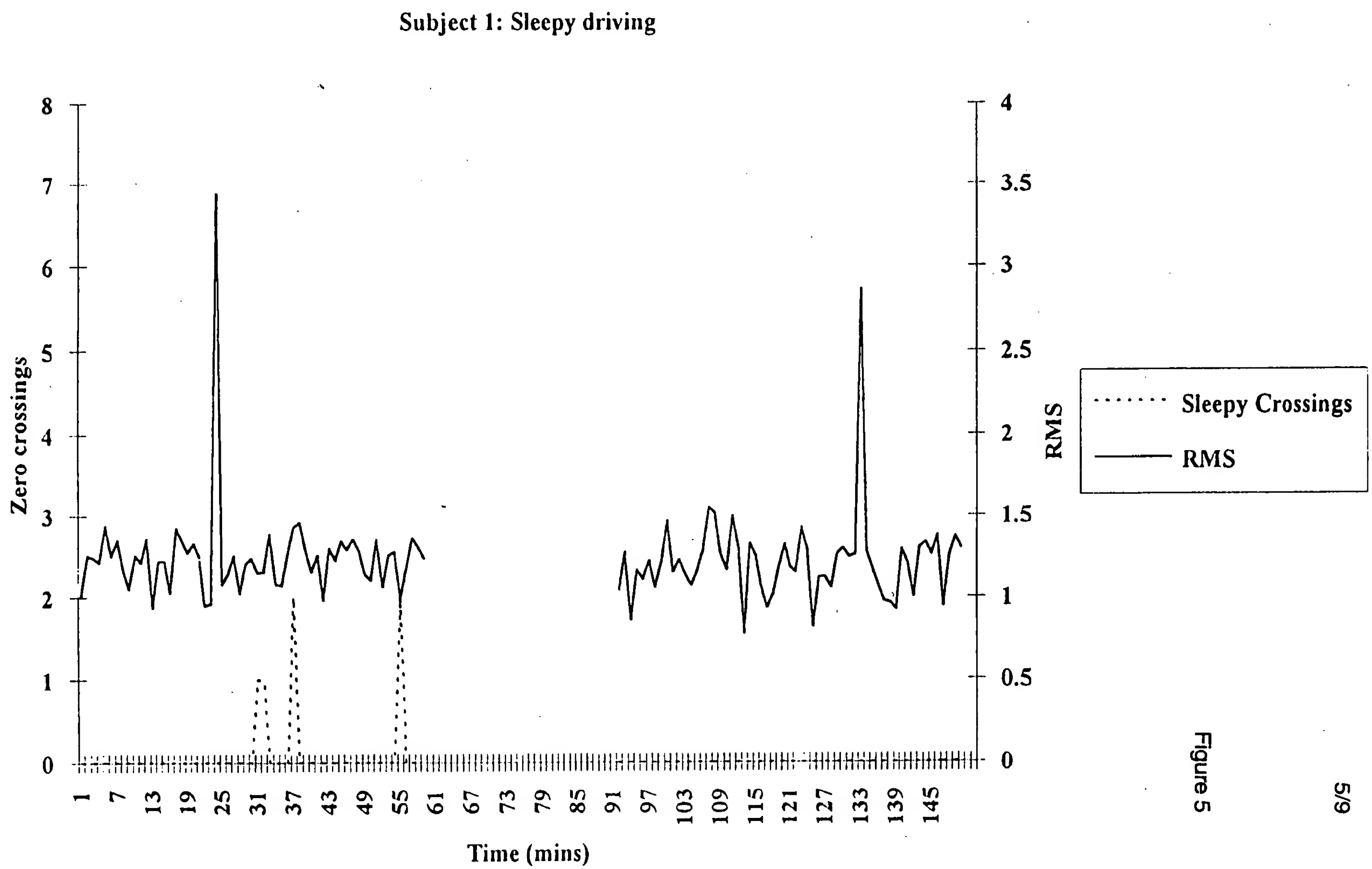
121


Subject 1: Sleepy driving
Zero crossings
RMS
Time (mins)
Sleepy Crossings
RMS
0
1
2
3
4
5
6
7
8
0.5
1.5
2.5
3.5
1
7
13
19
25
31
37
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97
103
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115
121
127
133
139
145

Figure 5

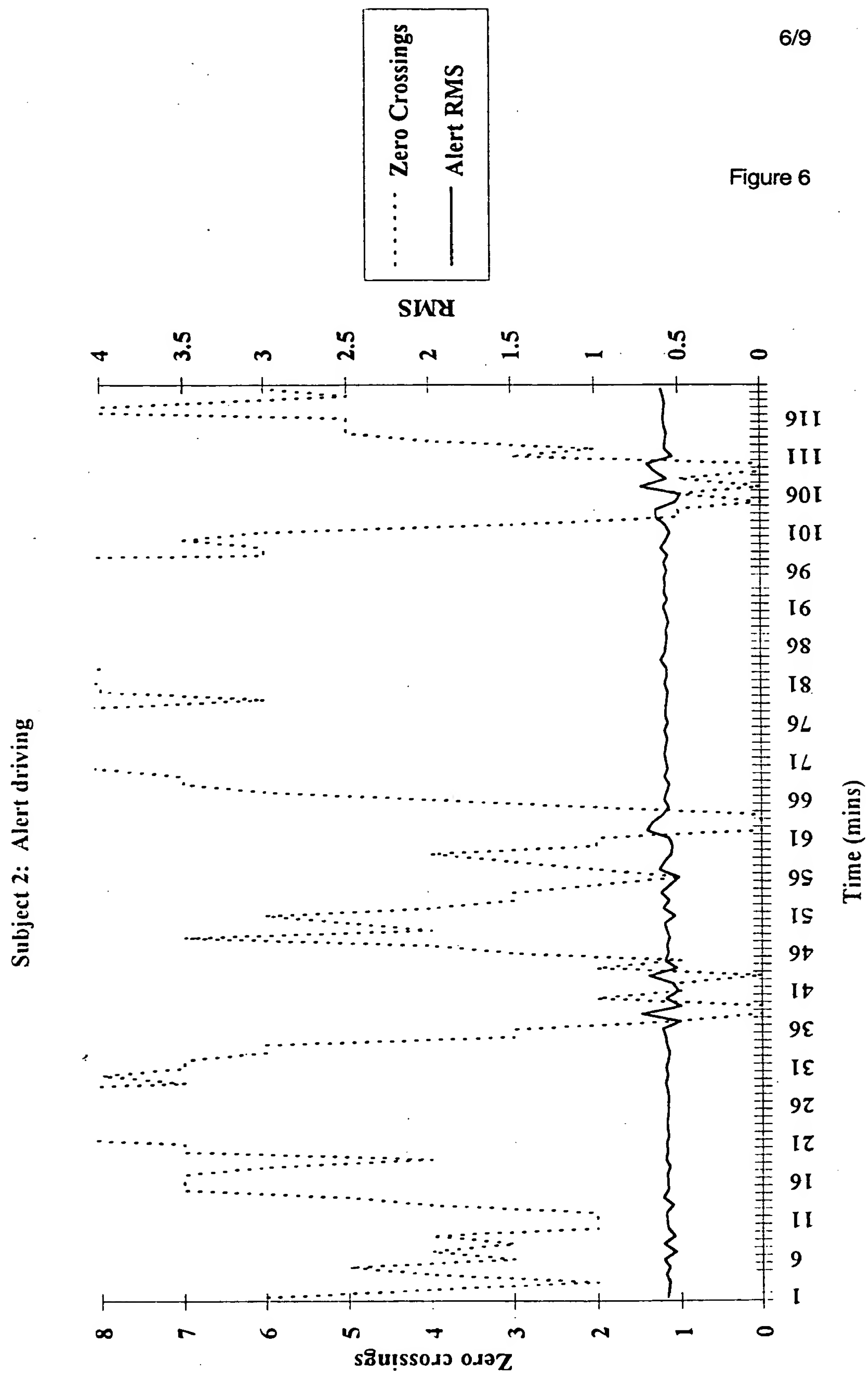
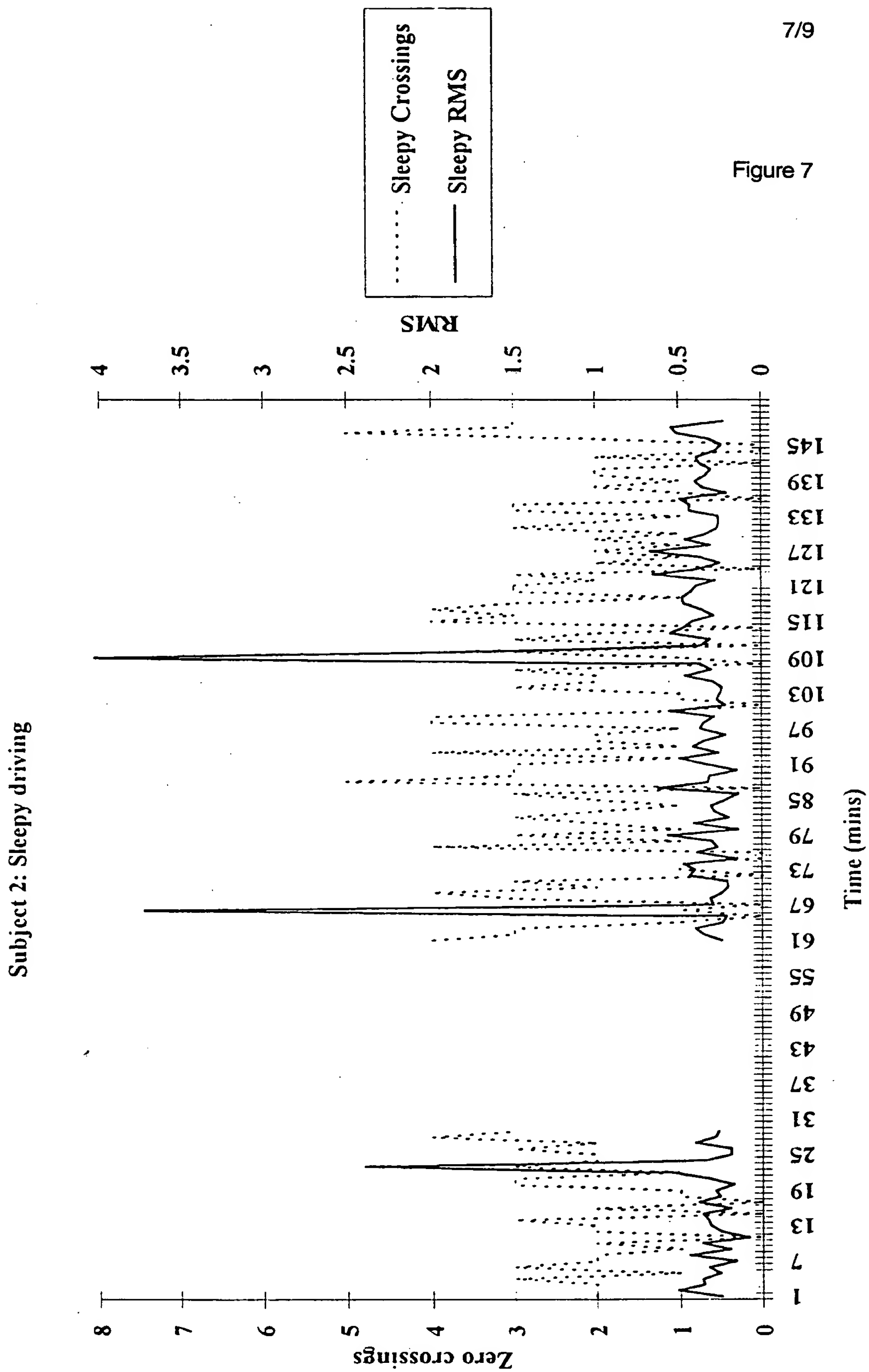
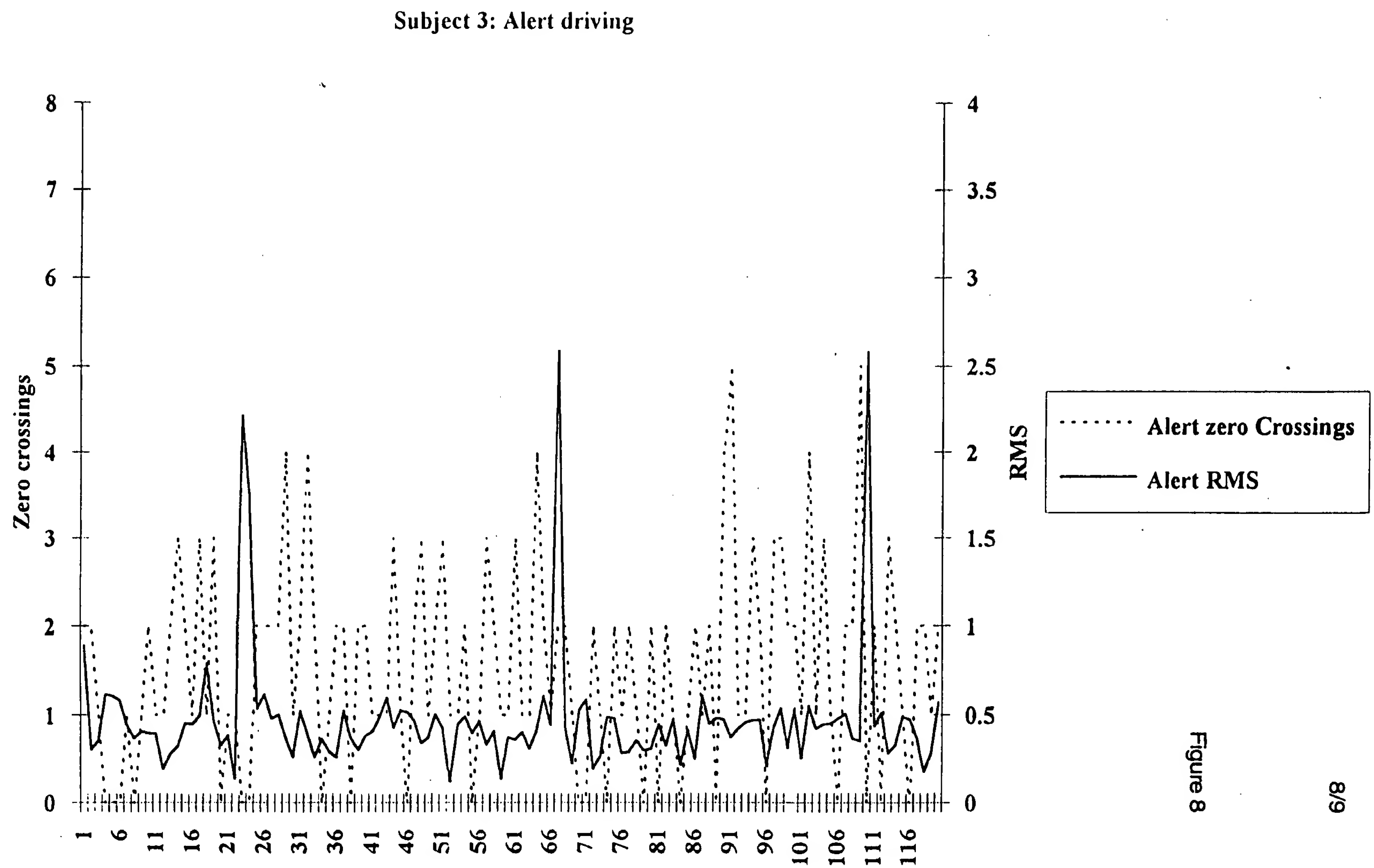

Subject 2: Alert driving
Zero crossings
8
7
6
5
4
3
2
1
0
RMS
4
3.5
3
2.5
2
1.5
1
0.5
0
Time (mins)
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
106
111
116
Zero Crossings
Alert RMS

Figure 6



Subject 2: Sleepy driving
Sleepy Crossings
Sleepy RMS
Zero crossings
0 1 2 3 4 5 6 7 8
RMS
0 0.5 1 1.5 2 2.5 3 3.5 4
Time (mins)
1 7 13 19 25 31 37 43 49 55 61 67 73 79 85 91 97 103 109 115 121 127 133 139 145

Figure 7


Subject 3: Alert driving
Zero crossings
RMS
Alert zero Crossings
Alert RMS
0
1
2
3
4
5
6
7
8
0.5
1.5
2.5
3.5
6
11
16
21
26
31
36
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111
116

Figure 8

Subject 3: Sleepy driving

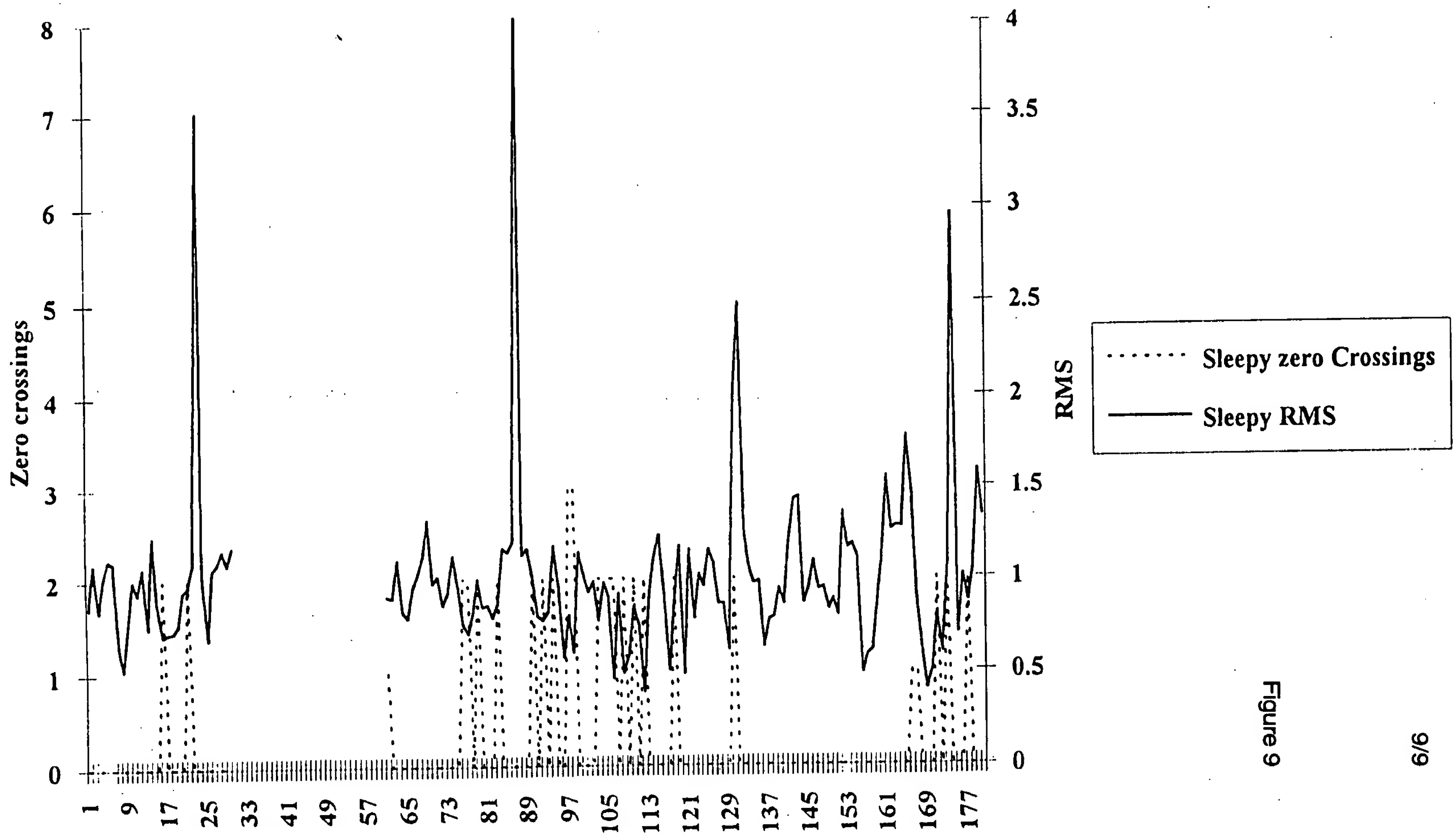

Figure 9